DISTURBANCE OF SOIL ORGANIC MATTER AND NITROGEN DYNAMICS: IMPLICATIONS FOR SOIL AND WATER QUALITY (CS-1114D-00)

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1. ACCOMPLISHMENTS SUMMARY

1.1 ORNL Team 2 had accomplishments during FY02 in the areas of: (1) presentations and publications, (2) field sampling, data analysis, and interpretation, and (3) research and development of models for the purpose of predicting thresholds in soil quality to ecosystem recovery and sustainability at Fort Benning, GA.

1.2 In the area of presentations and publications, ORNL Team 2 submitted two manuscripts for publication in peer-reviewed technical journals and presented posters at the SERDP Partners in Environmental Technology Technical Symposium and Workshop in Washington, DC (November 2001). Two white papers were prepared for the SEMP Technical Advisory Committee. The first was entitled "The ORNL Team 2 Resource Threshold Model: Model Development, Data Availability, and Potential Future Research Efforts". The second white paper was entitled "A Brief Review of the Threshold Concept in Ecology". Required SEMP quarterly reports and presentations of research progress for both the SEMP Technical Advisory Committee and the SERDP Scientific Advisory Board were competed on-time.

1.3 In the area of field sampling, data analysis, and interpretation, ORNL Team 2 submitted a data set to the SEMP data repository on the ECMI web site. We also completed pre-disturbance soil sampling at the K-11 training compartment in collaboration with ORNL Team 1 (Virginia Dale et al.), completed analysis of soil samples for soil carbon and nitrogen concentrations and stocks along a longleaf pine chronosequence, and completed a resampling of selected field sites to track recovery of soil carbon and nitrogen following site restoration activities by NRCS at Fort Benning.

1.4 In the area of model research and development, ORNL Team 2 completed work on a spreadsheet model to predict thresholds of soil quality to ecosystem recovery at Fort Benning, and we made significant progress on a multi-compartment model to predict the dynamics of plant biomass and soil quality. The latter model was used as part of an analysis of recovery potential and sustainability of forest ecosystems. We also initiated collaborations with the University of Florida to develop different approaches to hydrologic modeling of potential excess nitrogen on the Fort Benning landscape.

2. BACKGROUND

2.1 The deterioration of soil quality can lead to dramatic and long-term changes in terrestrial ecosystems, but little is currently known about what thresholds may exist that prolong or prohibit the recovery of soil quality following ecosystem disturbance. The mission of this project, within the framework of the SERDP Ecosystem Management Project (SEMP), is to evaluate the short- and long-term effects of land use change and terrestrial ecosystem disturbance on two key measures of soil quality: soil organic matter (i.e., soil carbon) and soil nitrogen dynamics.

2.2 ORNL Team 2 is conducting studies of soil carbon and nitrogen dynamics across a range of spatial scales at Fort Benning, Georgia. The most intensive studies are being performed in the K-11 training compartment where there are ongoing and planned ecosystem disturbances. Broader scale studies, at the installation level, involve sampling sites that are distributed across both upland and lowland terrain.

2.3 These studies are focused on the effects of military and forestry disturbances on key measures of soil quality as well as the potential recovery of soil quality following site disturbance. Our science questions are: (1) can soil carbon and nitrogen dynamics be used to identify nutrient resource thresholds to recovery of desired future ecosystem conditions at Fort Benning?, (2) how do disturbances associated with military activity and forestry affect measures of soil quality?, and which soil attributes and processes are good candidates for indicators of ecosystem disturbance and the identification of thresholds to recovery or sustainability?

3. OBJECTIVES

3.1 Carbon and nitrogen are important determinants of soil quality, which ultimately affects the recovery and sustainability of terrestrial ecosystems following ecosystem disturbance. Ecosystem recovery and sustainability are important elements of conservation efforts on military lands. The objectives of this research are to develop models of soil carbon and nitrogen dynamics, to predict soil quality thresholds to ecosystem recovery, and to evaluate the potential for recovery and sustainability of soil quality associated with different types of disturbance
.
3.2 The objectives of the study are being accomplished through the following research tasks:

1. characterize the effect of disturbances and land cover on key measures of soil quality (i.e., describe how soil carbon and nitrogen dynamics are affected by current DoD land use activities and natural disturbance regimes),

2. determine whether there are thresholds associated with natural and/or anthropogenic disturbance that establish the potential recovery of soil quality following site disturbance (i.e., describe how current DoD activities and/or land use activities affect the potential for short- to long-term recovery of soil quality in disturbed environments),

3. build simple dynamic models of soil carbon and nitrogen for different land cover categories to predict the recovery of soil quality on disturbed lands,

4. conduct long-term field experiments to calibrate and test models used to predict the recovery of soil quality (including soil carbon sequestration) following disturbance caused by DoD activities, and

5. use existing GIS resources as a tool for analysis of spatial patterns of soil carbon and nitrogen and as a basis for predicting the effect of site disturbance and/or land cover change on soil quality and nonpoint sources of nitrogen to surface water drainages.

4. APPROACH

4.1 The approach to the research involves a combination of field measurements and systems modelling. Field measurements from disturbance gradients, different land cover categories, and forest chronosequence sites have been used to build mathematical

models for predicting system response to disturbance and identifying thresholds to recovery following ecosystem disturbance. The models and the field data will also be used in combination with GIS data for a landscape level analysis of soil carbon and nitrogen stocks.

4.2 Field measurements of soil bulk density, soil carbon, and soil nitrogen dynamics have been made in ecosystems along gradients of disturbance and land use change (e.g., forests, old-fields, disturbed, and undisturbed lands) at Fort Benning, Georgia. Soil samples are usually collected to a depth of 40 cm and are divided into surface litter (O-horizon) and mineral soil. The mineral soil is further subdivided into 10 cm increments. The various portions are analyzed for total carbon and nitrogen concentrations. Soil nitrogen availability is determined by measuring potential net soil nitrogen mineralization under laboratory conditions. Soil carbon inventories are further partitioned into labile, organomineral, and refractory pools using laboratory techniques.

4.3 Soil samples have been collected along disturbance gradients, gradients of land use/land cover change, forest chronosequences, and forest sites set aside for future disturbance experiments. Information and data from the field studies has been incorporated into mathematical models of soil carbon and nitrogen dynamics. These models allow prediction of the recovery of soil quality at Fort Benning following site disturbance. The models also allow us to explore disturbance thresholds that possibly impact the potential for short- and long-term recovery of soil quality following site disturbance. We have also measured soil carbon and nitrogen stocks in ecosystems along gradients of disturbance and land use change for the purpose of mapping key measures of soil quality using a geographic information system.

5. PROGRESS SUMMARY FOR FIELD RESEARCH (FY02)

5.1 In general, connections between land cover and soil properties directly related to soil quality are not well established. In FY02, ORNL Team 2 completed an analysis of land cover differences in soil carbon and nitrogen and potential soil nitrogen availability at Fort Benning, Georgia. Forty-one sampling locations across the installation were classified into five major land cover categories: deciduous forest, mixed forest, evergreen forest or plantation, transitional herbaceous vegetation, and barren land. Land cover had a statistically significant effect on key measures of soil quality including

soil bulk density, nitrogen availability, soil carbon and nitrogen stocks, and properties and chemistry of the O-horizon.

5.2 Barren land had exceedingly poor soil quality relative to other land cover categories at Fort Benning. The creation of barren land, through disturbance by heavy vehicle loads and/or erosion, has resulted in significantly greater soil bulk density and a substantial loss of soil carbon and nitrogen relative to land under perennial vegetation. Measures of soil quality were often similar under transitional vegetation and forest cover indicating that ecosystem type is less important for the maintenance of soil quality than the mere presence of long-term perennial vegetation. We estimate that recovery of soil carbon under barren land at Fort Benning, to current day levels under transitional vegetation or forests, would require about 60 years following the reestablishment of perennial vegetation.

5.3 In October, 2001, ORNL Team 2 conducted autumn sampling at the K-11 Experimental Study Area at Fort Benning. Approximately 33 soil samples (and associated forest floor samples) were collected along a topographic gradient in conjunction with vegetation sampling by ORNL Team 1 (Dale et al.). The results of the autumn soil sampling will complement results from spring soil sampling at the K-11 study area by ORNL Team 2. The results indicated that soil carbon and nitrogen stocks, and soil nitrogen availability, is greater in the near stream environment than at upland sampling sites. The estimated turnover time for total carbon was 8.8 and 16.5 years, respectively, in upland and riparian soils.

5.4 In April, 2002, ORNL Team 2 visited Fort Benning for the purpose of gathering additional field data on measures of soil quality under longleaf pine stands and at NRCS restoration areas. Measurements of diameter at breast height (DBH) were made along 40 m transects in seven longleaf pine stands ranging in age from 5 to 82 years. Trees per hectare and basal area were calculated for each stand. Foliage and wood/stem biomass were predicted from DBH measurements using published allometric equations. The equations were only suitable for larger trees, consequently we were only able to estimate aboveground biomass density in the most mature longleaf pine stands (56 to 82 years). Estimates of AGBD in these stands ranged from 14 to 24 kg m-2. Nonlinear regression indicated an average maximum AGBD equivalent to 18300 g m-2.

5.5 Soil samples were collected along the longleaf pine chronosequence and at two previously barren sites that were

restored to herbaceous grasses in 2001. The latter sites had lost most of the herbaceous cover that was present in the prior year. A nitrogen fixer, Lespedeza, appears to be colonizing these previously barren sites following demise of the herbaceous grasses. An analysis of soil carbon and nitrogen concentrations and stocks at these sites was completed during FY02. The soil carbon and nitrogen stocks and the fraction of soil carbon in particulate organic matter were highest in the two oldest forest stands. A turnover time of 9 years was calculated for total soil carbon in the four oldest longleaf pine stands. Field data also indicate that there is a temporary decline in soil carbon stocks and an increase in soil nitrogen availability immediately after forest clear-cutting at Fort Benning.

5.6 Corona photographs from 1964 were used to determine land cover change at some of the ORNL Team 2 study sites. Sites that had been under forest cover or oldfield vegetation for 36+ years had similar soil carbon stocks. In addition, there was a clear increase in soil C:N ratios as secondary succession proceeded from barren land to oldfield vegetation to forest. Sites with a known history (as determined from historical photos) are valuable calibration points for modelling ecosystem recovery following site disturbance.

6. PROGRESS SUMMARY FOR MODEL DEVELOPMENT

6.1 During FY02, ORNL Team 2 continued work on the development of a nutrient threshold model for ecosystem recovery and sustainability at Fort Benning, Georgia. The concept underlying the nutrient threshold model to ecosystem recovery was described in presentations and a white paper prepared for review by the SEMP Technical Advisory Committee. The threshold modelling has evolved through an iterative process from a spreadsheet based model to an object oriented compartment model based on first-order differential equations. The latter model was developed using Stella modelling software (High Performance Systems Inc., Hanover, NH).

6.2 ORNL Team 2 used data from field studies under different land cover types at Fort Benning along with information from published literature to parameterize the resource threshold models that are based on soil nitrogen availability. The model asks a threshold question: Are soil nitrogen supplies sufficient to meet plant nitrogen demands and support growth to a desired future ecosystem condition? The primary distinction between the spreadsheet model and the dynamic compartment model

is that the latter includes a feedback from soil nitrogen availability to aboveground production of woody biomass.

6.3 Spreadsheet Model

6.3.1 The approach with the spreadsheet model includes calculations for the following submodels: (1) aboveground and belowground biomass, (2) soil carbon inputs and soil carbon dynamics, (3) soil nitrogen stocks and nitrogen availability, and (4) plant nitrogen requirements. A nutrient resource threshold is crossed whenever plant nitrogen requirements exceed soil nitrogen availability.

6.3.2 Thresholds in soil quality (defined by soil carbon stocks) to ecosystem recovery were calculated with the spreadsheet model for forests and oldfields at Fort Benning, Georgia. Thresholds predicted with the spreadsheet model depend on: (1) the desired future condition (i.e., target biomass), (2) the initial soil quality (g C m2), and (3) the recovery rate (i.e., the growth rate for aboveground plant biomass). For each case, indicated levels of recovery are attainable below the threshold line and are not attainable above it. A lower target (i.e., less biomass) lowers the threshold (initial soil carbon stock) to ecosystem recovery. Predicted thresholds to recovery of herbaceous vegetation are less than those for forests.

6.3.3 Thresholds in soil quality to ecosystem recovery predicted with the spreadsheet model are probably conservative (i.e., the thresholds to recovery based on soil carbon levels may be overestimated). There is a long tradition of making conservative predictions when models are used for the purpose of protecting the environment. Although it may error on the side of caution, the spreadsheet model delivers predictions that are useful for land management decisions.

6.4 Compartment Modelling

6.4.1 Several versions of the compartment model were written and evaluated during FY02. Each version was evaluated from the standpoint of conceptual structure (i.e., state variables and their relationships to one another) and data requirements (i.e., what information is needed to run simulations with the model). The objective behind the process of evaluation was to arrive at the simplest possible model structure that captured critical processes contributing to the accrual, decline, or sustainability of soil quality at Fort Benning and, at the same

time, permit prediction of thresholds to recovery of desired future ecosystem conditions.

6.4.2 The current version of the model includes only two state variables: (1) aboveground biomass density of woody vegetation, and (2) soil carbon stocks. All other attributes of the system (e.g., herbaceous biomass and soil nitrogen stocks) are predicted based on the status of these two state variables. Earlier versions of the model included a more detailed treatment of soil carbon dynamics (by separation into labile and stable soil carbon pools), but too many uncertainties in model parameterization precluded this level of detail. The compartment model includes a feedback of soil nitrogen availability on tree growth rate. Prescribed fire and clear-cutting were included as disturbance events in the model.

6.4.3 Several different scenarios in ecosystem sustainability have been predicted with the compartment model, including: (1) sustainability of forestry practices (harvesting and prescribed burning), (2) ecosystem recovery from degraded soils, and (3) the effect of land cover change (deforestation) on soil quality. These scenarios indicate that forest harvesting (50 year rotation) and prescribed burning have only temporary effects on soil quality which are manifested as a relatively small decline in soil carbon stocks. The predicted effect of land cover change, from forest to oldfield, is a small decline in soil carbon stocks and an increase in potential excess nitrogen in the ecosystem. Simulations with the compartment model indicated that prescribed fires with a frequency of 2 years or less may significantly depress aboveground tree biomass density in forest ecosystems.

6.4.4 There are many aspects of carbon and nitrogen biogeochemistry that can be incorporated into the concept of thresholds to ecosystem recovery or sustainability. One advantage of modelling is the ability to predict ecosystem response over a broad range of hypothetical disturbance levels. Notable disadvantages are the availability of data and knowing the system well enough to arrive at an accurate model structure. Despite some limitations, modelling is valuable tool for analyzing conservation issues related to military land management, restoration of vegetation, and ecosystem sustainability.

7. DATA REPORTING AND WHITE PAPERS

7.1 Data Reporting

7.1.1 In December, 2001, ORNL Team 2 submitted data files from the first year of work at Fort Benning to the SEMP data repository on the ECMI web site. These files included both metadata and data files for studies of soil carbon and nitrogen (and particulate and mineral-associated organic matter) along a disturbance gradient established by ORNL Team 1 in September and October of 1999. The same data have also been summarized in a publication that was submitted to the journal Ecological Indicators.

7.2 White Papers

7.2.1 In November, 2001, the SEMP Technical Advisory committee requested that Beverly Collins (SREL) and Chuck Garten (ORNL) "develop shared concepts of thresholds in terms of both ecological and managed use goals" for their research projects at Fort Benning. An additional related request was that both teams write short white papers to identify potential future research efforts beyond each project's last year of funding.

7.2.2 In response to these requests, Garten and Collins prepared a white paper entitled A Brief Review of the Threshold Concept in Ecology. The report summarized several important points that the Technical Advisory Committee felt required clarification, including: (1) the current understanding of ecological thresholds, (2) examples of the use of thresholds in ecosystem management, (3) a discussion of how thresholds vary depending on management goals, and (4) a conceptual basis for linking research on ecological thresholds and indicators. The white paper concludes that SREL and ORNL Team 2 are identifying thresholds of ecosystem sustainability and potential for recovery within a unified threshold concept. The unified concept includes both changes in biogeochemical cycling and the structure/composition of plant communities in response to ecosystem disturbance. A table in the report summarizes the connections between ecological indicators and the threshold concept.

7.2.3 In response to a request from the Technical Advisory Committee directed specifically to ORNL Team 2, Garten and Ashwood prepared a report entitled The ORNL Team 2 Resource Threshold Model: Model Development, Data Availability, and Potential Future Research Efforts. The purposes of the white paper were to: present the rationale for research and development of a mathematical model to predict thresholds to desired future ecosystem conditions, identify the data needed to

apply a resource threshold model at Fort Benning, identify the opportunities where current and planned research projects can be used to supply data to improve parameterization of the model, and identify potential future research efforts by ORNL that will help to supply the data needed to successfully apply the model to land management decisions at Fort Benning.

7.2.4 The latter document reviewed data availability for the ORNL threshold model, and relevant local values for standing crop biomass in different ecosystems at Fort Benning. The paper also described the components of the spreadsheet version of the model (biomass dynamics, soil carbon dynamics, soil carbon and nitrogen stocks, plant nitrogen requirements). Equations and example results were presented for loblolly pine as a desired future ecosystem condition at Fort Benning. Data needs and deficiencies were identified, including site specific information on target aboveground biomass values, growth rates for different forest types, rates of net soil nitrogen mineralization, plant tissue nitrogen concentrations, and the biomass dynamics and nutrient contents of herbaceous vegetation.

8. COLLABORATIONS

8.1 Aside from collaborations with SREL on the "Thresholds White Paper", ORNL Team 2 was involved in a number of collaborations with other SEMP researchers. As indicated previously, ORNL Team 2 coordinated pre-disturbance soil sampling in training compartment K-11 with vegetation sampling by ORNL Team 1 (Dale et al.). ORNL Team 2 also held discussions with two other SEMP research groups about potential future collaborations. Discussions were held with Beverly Collins, SREL, about plans to prepare a joint proposal for an extension of thresholds research at Fort Benning, and with Jennifer Jacobs, University of Florida, about building a landscape level hydrologic model of excess soil nitrogen.

8.2 In August, 2002, Tom Ashwood and Chuck Garten met with Dr. Jennifer Jacobs and Shirish Bhat at the University of Florida, Gainesville, to discuss possible collaborations between the two SEMP research projects. The teams exchanged information on projects goals with respect to modelling and explored several different approaches to hydrologic modelling of potential excess nitrogen on the Fort Benning landscape. Shirish Bhat plans to use some of the ORNL Team 2 data from a landscape level mass balance model of nitrogen cycling in completing a research project for his doctoral dissertation. Tom Ashwood has developed a plan for using simple GIS tools to approximate

nitrogen loading to Fort Benning streams from a quantitative assessment of potential excess nitrogen on the terrestrial landscape. This plan represents the foundation to accomplish the final research task associated with the ORNL Team 2 research project. Thus, we are on schedule for completion of all major tasks outlined in the original proposal.

9. PRODUCTS

ORNL Team 2 submitted two manuscripts for publication in FY02 and made several platform or poster presentations at meetings.

9.1 Presentations and Posters

Garten, C.T., Jr. Disturbance of soil organic matter and nitrogen dynamics: implications for soil and water quality. Platform presentation, SEMP Research Coordination Meeting, 6 Nov 2001, Columbus, GA

Garten, C.T., Jr. Disturbance of soil organic matter and nitrogen dynamics: implications for soil and water quality. Platform presentation, SEMP Technical Advisory Committee Meeting, 8 Nov 2001, Columbus, GA

Ashwood, T.L., and C.T. Garten, Jr. Effect of military training on indicators of soil quality at Fort Benning, Georgia. Poster presentation, SERDP Partners in Environmental Technology Technical Symposium and Workshop, 27 Nov 2001, Washington, DC

Ashwood, T.L., and C.T. Garten, Jr. Disturbance of soil organic matter and nitrogen dynamics: implications for soil and water quality. Poster presentation, SERDP Partners in Environmental Technology Technical Symposium and Workshop, 27 Nov 2001, Washington, DC

9.2 Papers Submitted for Publication

Garten, C.T., Jr., and T.L. Ashwood. Effect of military training on indicators of soil quality at Fort Benning, Georgia. Ecological Indicators (submitted for publication Dec 2001)

Garten, C.T., Jr., and T.L. Ashwood. Land cover differences in soil carbon and nitrogen at Fort Benning, Georgia. Environmental Management (submitted for publication May 2002)

9.3 White Papers

Garten, C.T., Jr., and T.L. Ashwood. The ORNL Team 2 Resource Threshold Model: Model Development, Data Availability, and Potential Future Research Efforts. White Paper prepared for the SEMP Technical Advisory Committee, Feb 2002, 18 pages.

Garten, C.T., Jr., and B. Collins. A Brief Review of the Threshold Concept in Ecology. White Paper prepared for the SEMP Technical Advisory Committee, Sep 2002, 13 pages.

10. MILESTONES

Milestones for FY02 and their current status are summarized below.

Milestone: Preliminary analyses of soil measurements along gradients (Oct 2001). Status: The data set was completed and the information was presented by Chuck Garten at the November, 2001, meeting of the SEMP Technical Advisory Committee.

Milestone: Progress reports and annual reports (Oct 2001). Status: Progress reports by ORNL Team 2 were completed and submitted on schedule.

Milestone: Complete pre-treatment soil sampling at the K-11 experimental area (Dec 2001). Status: Soil sampling by ORNL Team 2 in October, 2001, completed the required pre-treatment soil sampling at the K-11 experimental site.

Milestone: Complete development of a preliminary model to predict disturbance thresholds for soil quality at Fort Benning (Feb 2002). Status: A report to the SEMP Technical Advisory Committee regarding the ORNL Team 2 threshold model completed the development of a preliminary spreadsheet model to predict disturbance thresholds for soil quality at Fort Benning.

Milestone: Complete resampling of selected field sites to track recovery of measures of soil quality following site restoration activities. Status: The task was completed April 30, 2002.

Milestone: Evaluate and interpret the importance of different LULC categories as nonpoint sources of N to

surface receiving waters (Sep 2002). Status: According to plan, this milestone was not completed. ORNL Team 2 changed the plan to address this milestone in the SEMP FY02 Execution Plan, and the reasons for the proposed change were outlined in the plan. The milestone was deferred until FY03. ORNL Team 2 has recently started the work required to meet this milestone by September 2003.

Milestone: Nitrogen mineralization study in collaboration with C. Garten (Sep 2002). Status: This was a joint milestone with SREL. Instrument problems at ORNL have led to a delay the analysis and interpretation of results from laboratory incubations to estimate potential net soil nitrogen mineralization in different environments at Fort Benning. Consequently, ORNL Team 2 has not yet completed the data set required to meet this milestone. We hope to have the data completed by the end of March 2003.